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PERFORMANCE OF COATED CEMENTED CARBIDE DRILLS IN DRILLING OF GRAY CAST IRON UNDER DIFFERENT LUBRI-COOLING CONDITIONS

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Abstract. *This paper aims at analyzing the performance of coated (TiN, TiAlN, TiAlCrN) cemented carbide drills with 6 mm of diameter, in machining of gray cast iron. The input variables, besides the coatings, were the hole length (8, 14 and 20 mm), the lubri-cooling system (dry drilling, application of minimum quantity lubrication-MQL, conventional overhead flood cooling and compressed air) and the cutting speed (25 and 50 m/min). The output parameters considered were the thrust force (F_z) and torque (M_z). ANOVA was used to evaluate the results and with a reliability index of 95%, it was found that the lubri-cooling system was the most significant variable that affect the thrust force, considering both the isolated effect and interactions. The length of the hole, considering only its isolated effect, was the most influential variable in the torque, however, when considering the interactions, the combination of the lubri-cooling system with the drill coating overcame the effect of the drilling length. Among the tested lubri-cooling system, dry drilling was the condition that most increased the thrust force and torque and the machining with compressed air, in general, was the condition that most reduced them. Finally, in relation to the performance of the coatings, TiAlCrN and TiAlN drills, in general, gave smaller values of F_z and M_z , respectively.*

Keywords: *coated drill, lubri-cooling system, thrust force, torque, drilling of gray cast iron*

1. INTRODUCTION

Factors related to ecological issues have led many manufacturing companies, especially those from the metalworking industry, to review their processes, driving them toward "cleaner production". In response to this effort, new work alternatives have emerged, such as dry machining and the application of Minimum Quantity of Lubricant (MQL). These techniques are being increasingly used, somehow because of the development of work materials with improved machinability and also because a high development on tools materials, coatings and geometries that increase their resistance to wear and allow them to work at high temperatures, compensating even the lack of lubricant-cooling media in the machining processes (Jayal et al., 2010; Costa et al., 2015; Machado et al., 2015; Costa, 2004).

MQL system can be defined as the spraying of a minimum amount of lubricant in a stream of compressed air (Machado and Diniz, 2000). These small quantities of liquid is sufficient to substantially reduce friction on the tool and to prevent adhesion of the work material, since the tool-chip contact area is very small, which suggests that the oil flow needed to promote lubrication is also small (Costa et al., 2009).

The coatings on cutting tools have the main objective of increasing the tool life or the cutting speed, resulting in higher productivity. This is possible because the coatings are generally harder and can resist more the wear than uncoated tools. They also usually present lower friction that reduces the shear forces (and power consumption) and the tendency of adhesion of work material (Hogmark et al., 2000).

The greater the length of the hole, the greater is the difficulty in machining it, since the penetration of the cutting fluid from external application is reduced and removal of the chips from the hole becomes more difficult. These effects increase the friction in the cutting regions and consequently the thrust force and torque, with direct reflexes on the hole quality (Ramos et al., 2017; Costa, 2004; Santos, 2002).

The cutting force depends particularly on the shear strength of the work material and is predominantly responsible for the torque acting on the drill. The thrust (or feed) force depends on the performance of the chisel edge (extruding the work material, allowing penetration of the drill into the workpiece) and on the shear strength of the work material. The friction of the drill margins and the chips onto the hole wall also contributes to the increased thrust force and torque. This contribution depends on the quality of drill surfaces (obtained by grinding) and of the cutting fluid used (Costa et al., 2015, De Castro, 2001; Sandvik Coromant, 1994; Teixeira, 1995).

This work analyzed the performance of TiN, TiAlN and TiAlCrN cemented carbide coated drills, using the statistical technique of analysis of variance (ANOVA). The performance evaluation parameters were the trust force and torque. The input variables, besides the drill coatings, were the cutting speed; the drilling length and the lubri-cooling system.

2. METHODOLOGY

2.1. Strategies for drilling tests

The experiments consisted of machining blind holes using cemented carbide drills coated with TiN, TiAlN and TiAlCrN. These tools with diameter of 6 mm were used to drill gray cast iron with three different drilling lengths (8, 14 e 20 mm). Drilling tests were performed in a 3-axis vertical machining center, Discovery 760 Romi-Bridgeport, with 9 kW of power and maximum spindle speed of 10,000 rpm.

The work material was the pearlite FC 300 gray cast iron with addition of 0.2 % of Mo and refined graphite in the form of plates with dimensions of 240 mm x 300 mm x 36 mm. It has an average hardness of 217 HB and UTS of 283 MPa.

Besides the coatings and drilling lengths, the following input parameters were also varied: the lubri-cooling systems (dry drilling, application of minimum quantity lubrication-MQL, conventional overhead flood cooling and compressed air) and cutting speeds (15 and 25 m/min). Analysis of Variance (ANOVA) with a reliability of 95% was used in order to have statistical reliability on the results. For this, the STATISTICA® 12 software was used.

The combination of the input variables resulted in 72 cutting conditions, that is, 72 tests. Considering that each test consisted of three holes in sequence (test and two replicates) the total of 216 holes were machined and a distance of 9 mm between the centers of the holes was maintained. Table 1 shows details of input variables investigated.

Table 1. Input and output variables of drilling tests.

VARIABLES		VALUE	
INPUT	coating	TiAlN, TiN, TiAlCrN	
	drilling length (mm)	8, 14, 20	
	lubri-cooling system	dry drilling (atmospheric air)	-
		compressed air (bar)	9
		flood cooling-FC (930 L/h)	930
		minimum quantity lubrication-MQL (m/h)	22
cutting speed (m/min)	25, 50		
OUTPUT	THRUST FORCE-Fz (N)		
	TORQUE-Mz (N.m)		

Tests were carried out under 4 different lubri-cooling systems (atmospheres), namely: dry drilling (in which only the atmospheric air is present), application of compressed air at an average pressure of 9 bar, machining with applying of minimum quantity of lubricant (MQL) and machining with conventional overhead flood cooling. The cutting fluids and the compressed air were applied externally to the tool through nozzles positioned on top of the workpiece.

For the application of MQL a neat oil (Accu-Lube LB2000, manufactured by ITW Chemical Products Ltda) was used at a flow rate of 22 ml/h. This fluid, biodegradable and non-toxic, is a chemical mix of vegetable oils (soybean, corn and canola) and anticorrosive additives. The oil spray device used was the O2AO-STD model, manufactured by

ITW Chemical Products Ltda, which works with a continuous flow of compressed air, set around 0.5 MPa (5 bar) of pressure.

For the flood cooling system the cutting fluid used was a vegetal oil-based micro-emulsion (specification Vasco 7000[®], manufactured by Blaser Swissslube Inc) at a concentration of 8%, with an average flow rate of 930 L/h. In this case the pumping system of the Machining Center was used.

Figures 1-a and 1-b show the position of the nozzles for the application of the cutting fluids in the flood cooling and MQL systems, respectively, and Fig. 1-c shows the setup for the dry drilling condition.

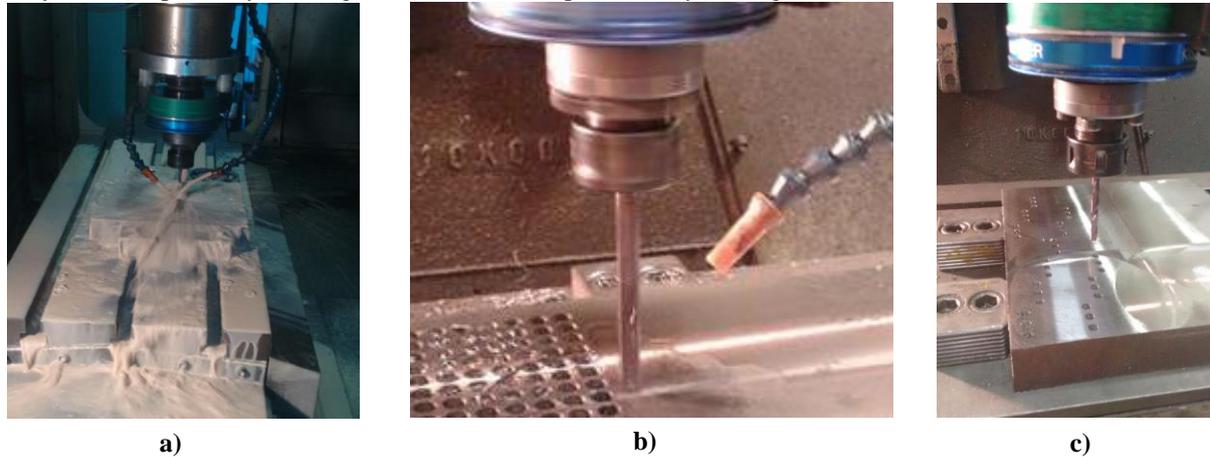


Figure 1. Application of lubri-cooling systems. a) flood cooling, b) minimum quantity of lubricant (MQL); c) dry drilling.

2.2. Evaluated output parameters - thrust force and torque

For monitoring the thrust force (F_z) and torque (M_z) a rotating piezoelectric dynamometer, model 9123C, with an amplifier and a signal conditioner, model 5223 (both manufactured by Kistler Instrumente Inc), a data acquisition board and Labview 7.6 software (both manufactured by National Instrument) were used. The acquisition of the thrust force and torque signals occurred during all the machining of the hole, with a rate of 1 kHz. Figure 2 shows schematically this measuring system. As three holes were machined for each test, the average values of F_z and M_z was assigned to the test.

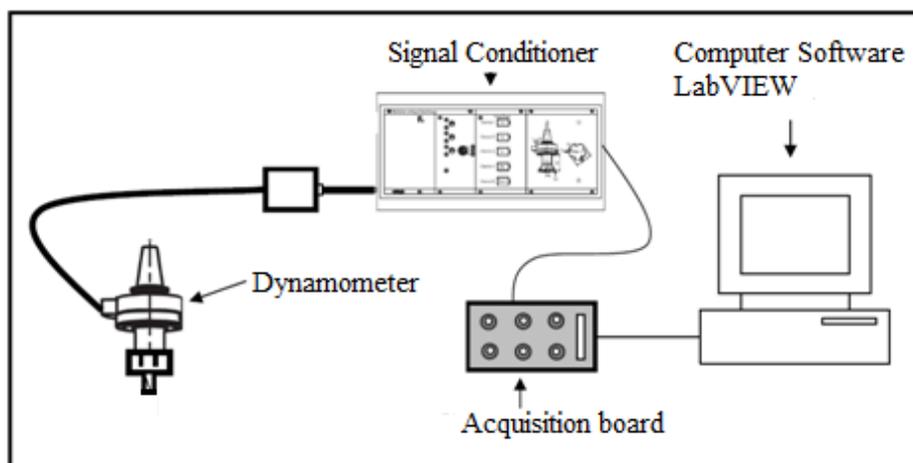


Figure 2. Schematic diagram of the thrust force and torque measuring system.

3. RESULTS E DISCUSIONS

Table 2 shows the order of influence of the input variables on F_z and M_z encountered after applying ANOVA. In this table only the main effects are present, that is, the interactions were not considered. The input variables in red have the value "p-value" smaller than 0.05, that is, they are statistically significant for a reliability index of 95%. This in

practice means that changing the level of these variables yields statistically different results in Fz / Mz. It should be pointed out that the smaller the "p-value", the more influential is the variable.

It is observed in Tab. 2 that the variable with the greatest effect in Fz is the lubri-cooling system. The length of the hole produced extreme effects in Fz and Mz, while in Fz it was the least influential in Mz was the most important. The coating of the drill was the third statistically most significant variable in Fz, and although not statistically significant for Mz it came in second place of significance, with a value "p-value" relatively close to 0.05 (0.068755). Finally, the input variables influenced much more Fz than Mz, due to the low "p-values" and the greater number of significant variables observed in the responses.

Table 2. Order of significance of the input variables in Fz and Mz.

Order	Input Variable ("p-value")	
	Fz	Mz
1st	lubri-cooling system (0.000003)	length of hole (0.012664)
2nd	cutting speed (0.000023)	coating (0.068755)
3rd	coating (0.001267)	lubri-cooling system (0.322295)
4rd	length of hole (0.173536)	cutting speed (0.401736)

In order to analyse the order of importance of the interactions between the input variables, ANOVA was also used. However, the variables with the smallest effect in Fz and Mz, that is, the hole length and cutting speed, respectively were excluded in the analyse. This strategy, besides facilitating the analysis, has limited the interactions to only three factors. Table 3 shows the new order of influence of the main variables and interactions using ANOVA for the three most important variables for Fz and Mz.

Table 3. Order of importance of input variables and their interactions in Fz and Mz.

Order	Input Variable ("p" value)	
	Fz	Mz
1st	lubri-cooling system (0.000000)	Interaction: lubri-cooling system*coating (0.001559)
2nd	cutting speed (0.000002)	Hole length (0.002027)
3rd	coating (0.000177)	coating (0.019302)
4rd	Interaction: lubri-cooling system*cutting speed (0.003639)	Interaction: Hole length*coating (0.011014)
5rd	Interaction: lubri-cooling system*cutting speed*coating (0.006063)	Interaction: lubri-cooling system*Hole length (0.048828)

When excluding the least significant input variable from the ANOVA and considering all interactions between the other variables, the number of variables / interactions that are significant ("p-value" < 0.05) increased to five, for both Fz and Mz (Tab. 3).

The order of classification of the variables for the first three positions was not changed to Fz, being in ascending order: tol coating, cutting speed and lubri-cooling system. For the fourth and fifth positions, interactions are observed in which the lubri-cooling system is present. On the other hand, when analysing the torque (Mz) the order of classification was altered, and the interaction between the coating and the lubri-cooling system, which in the isolated analysis were at the second and third positions, respectively (Table 2), reached the first place, surpassing the first position of the hole length in the first analysis. In the other variable interactions observed for Mz the hole length was always present.

Overall, the results presented in Table 3 showed that the lubri-cooling system was the most important input variable influencing Fz and Mz, by the following arguments: In relation to Fz is the most influential variable and when interacting with the drill coating, has become the condition that most affects Mz. On the top of that, in the five interactions identified as significant in Fz / Mz, the lubri-cooling system was in four of them.

3.1. Behaviour of the input variables in the thrust force (Fz)

Figure 3 shows the behaviour of the thrust force as a function of the lubri-cooling system and the cutting speed. In this figure it is clear that when increasing the cutting speed F_z decreased regardless the lubri-cooling systems used. This is because increasing the cutting speed, greater heat is generated, increasing the cutting temperature, which reduces the strength of the work material, facilitating deformation in the shear zones and in the extruding region (centre of the hole) and consequently reducing the thrust force.

Among the lubri-cooling systems studied, dry drilling was the condition that most increased F_z . Application of compressed air stands out in the results of the thrust force with the superior performance, in general. The drilling systems that applied cutting fluids showed close performances and resulted in F_z values well below the dry condition.

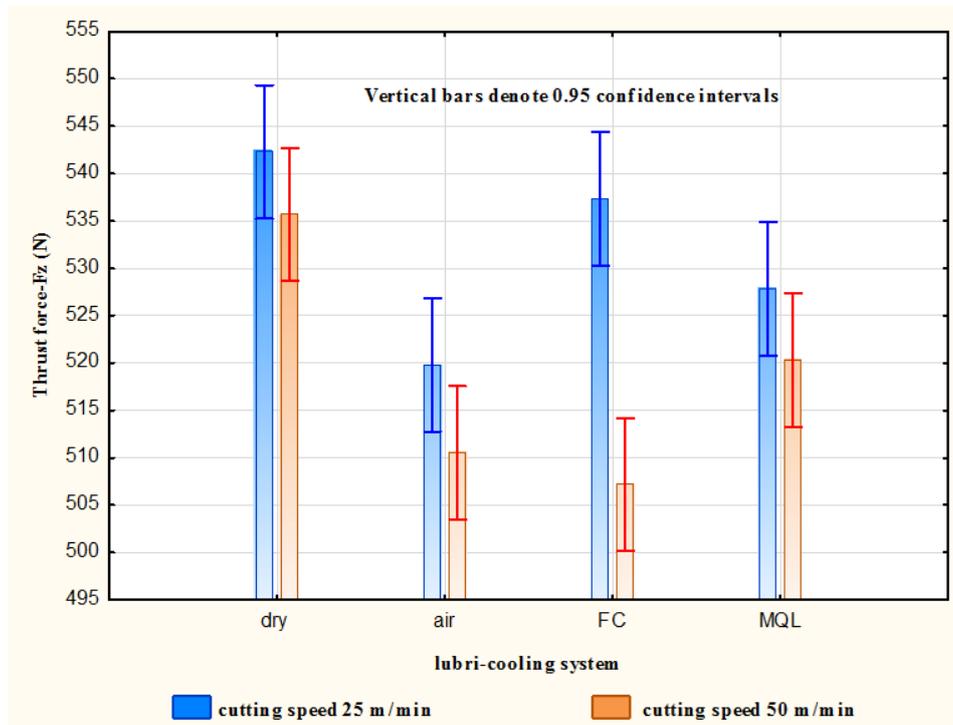


Figure 3. Influence of the lubri-cooling system and cutting speed on the thrust force F_z .

Figure 4, which shows the behaviour of F_z as a function of the drill coating and the lubri-cooling system, clearly indicates that dry machining produced the highest F_z values, compressed air the lowest, and machining with MQL systems and flood cooling intermediate values.

Analysing the performance of the tool coatings, TiN gave the highest values of F_z and TiAlCrN, generally the lowest. It can also be stated that the TiAlN coating provided, in general, more stable average values of F_z , that is, this coating promoted average variations in F_z less abrupt when the lubricant-refrigerant system was changed, Fig 4 compared to the other two coatings.

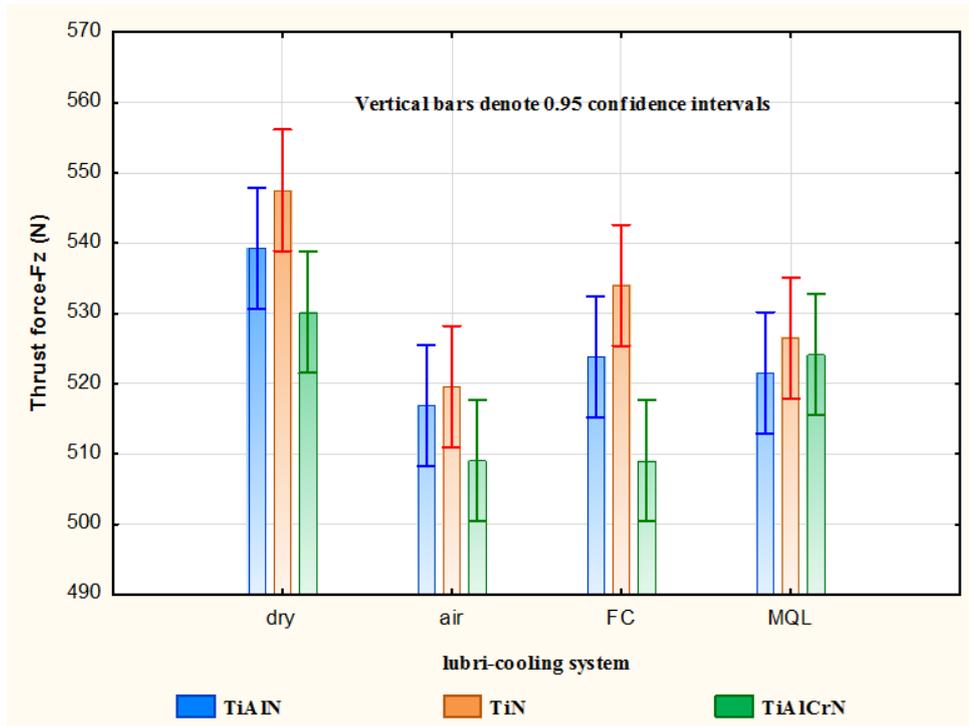


Figure 4. Influence of the lubri-cooling system and tool coating on the thrust force F_z .

3.2. Behaviour of the input variables in the torque (M_z)

Figure 5 shows the torque behaviour in relation to the lubri-cooling systems and cutting tool coatings. In general, dry drilling produced the highest values of the torque and compressed air the smallest ones, same trend observed in F_z .

Intermediate results were recorded for machining with the MQL and flood cooling systems that resulted in values relatively close to each other. Figure 6 shows the influence of the lubri-cooling system on the average results of the torque (M_z) considering all the tests.

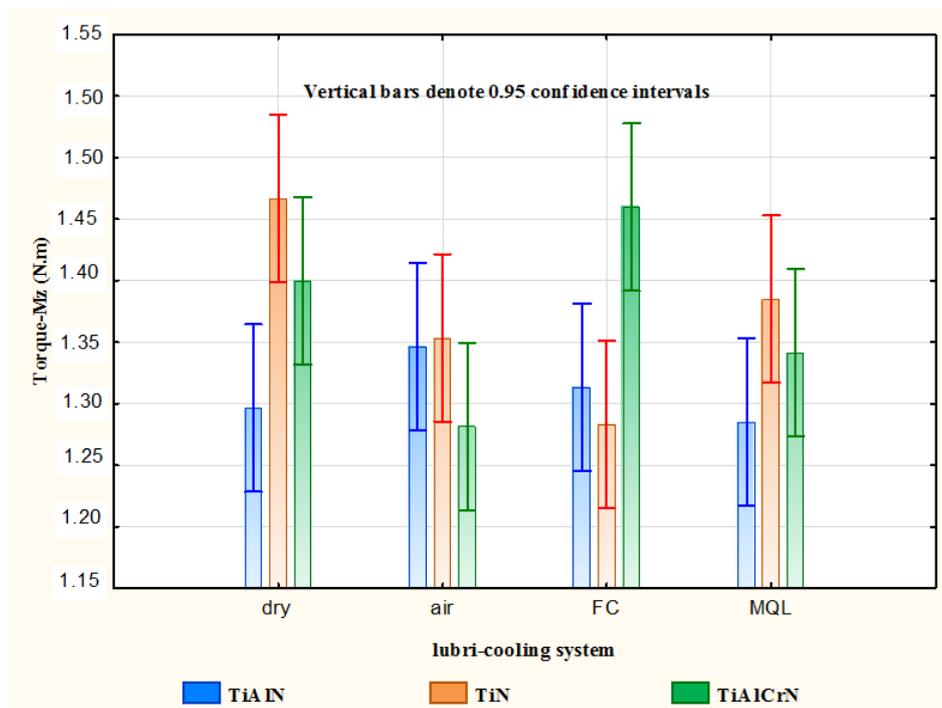


Figure 5. Influence of the lubri-cooling system and the coating on the torque.

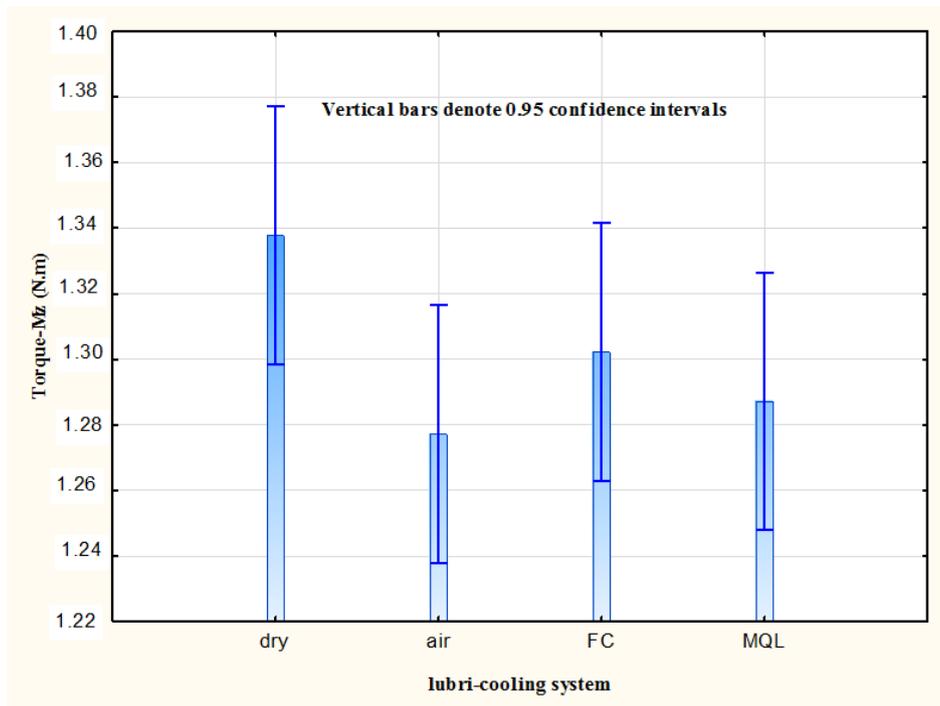


Figure 6. Influence of the lubri-cooling system on the torque considering all the tests.

The fact that drilling with application of compressed air has shown better results for both F_z and M_z than the other lubri-cooling systems seems to be associated with the high power that this condition has to drive out the short chips produced in the machining of the gray cast iron from the cutting region, since the compressed air was directed in the cutting region with a relatively high pressure (9 bar). It should be noted that the air pressure used in the MQL system was only 5 bar, however, enough to put this system in the second position in reducing the forces.

Figure 7 shows the effect of the hole length and tool coatings on the torque (M_z). As also seen in Fig. 5, generally, the best results are presented by the TiAlN, followed by TiAlCrN and then by the TiN coating. Exception of this trend is when machining deeper holes (hole length of 20 mm), where the TiAlCrN coating presented the highest values of torque.

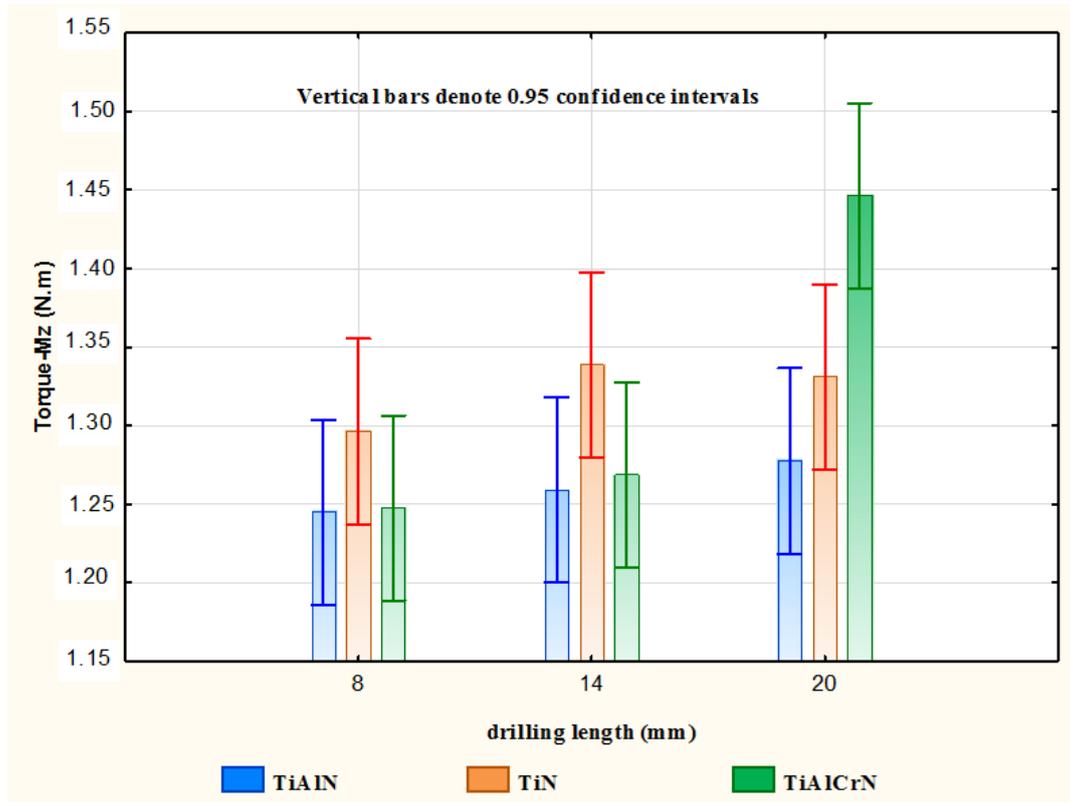


Figure 7. Influence of the hole length and tool coating on the torque Mz.

The hole length variable was extremely important and statistically significant in the Mz results, as seen in Tabs. 2 and 3. Figure 7 also makes clear that the torque tends to increase as the hole length increases. This is because the chips have more difficulties to come out and the cutting fluids more difficulties to reach the cutting region for deeper holes (Machado et al., 2015; Ramos et al., 2017).

4. CONCLUSIONS

In view of the results obtained from the drilling tests, the main conclusions of this work are:

- Among the input variables, the lubri-cooling system was the one that most influenced the thrust force, considering isolated effect and interactions.
- The hole length, considering only the isolated effect, was the most influential variable on the torque and the least influent in the thrust force.
- The interaction between the drill coating and the lubri-cooling system resulted in the most important effect on Mz, being more important than the hole length.
- Among the tested lubri-cooling systems, dry drilling was the condition that showed highest forces, and the compressed air, in general, the most efficient in reducing them.
- MQL and flood cooling systems produced, in general, values of Fz and Mz relatively close and always intermediate to dry and compressed air systems.
- The drill with TiN coating always produced the highest values of Fz and, in general, the higher values of Mz.
- The TiAlCrN and TiAlN coatings, in general, presented the best performances in reducing Fz and Mz, respectively.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

- Costa, E.S. 2004, "Furação de Aços Microligados com Aplicação de Mínima Quantidade de Fluido de Corte-MQF". Tese Doutorado, Universidade Federal de Uberlândia-MG, 2004, 311p.

- Costa, E.S. ; Da Silva, M.B. ; Da Silva, R.B. . “Burr produced on the drilling process as a function of tool wear and lubricant-coolant conditions”. *Journal of the Brazilian Society of Mechanical Sciences and Engineering (Impresso)*, v. 31, p. 57-63, 2009.
- Costa, E.S., Martins, M.C., Sales, W.F. and Machado, A.R., 2015. “Effect of the Access of Ambient Air in Drilling of Steel”. In *In Proceedings of the 2rd International Congress of Mechanical Engineering - COBEM2015*. Rio de Janeiro, Brazil.
- De Castro, P.R.A., 2001. “Aspectos Tecnológicos da Usinagem a Seco e com Mínima Quantidade de Fluido de Corte na Furação com Broca Helicoidal”, Dissertação de Mestrado do Programa de Pós-Graduação em Eng. Mecânica da UFSC, Florianópolis-SC ,178 p.
- Hogmark, S.; Jacobson, S.; Larson, M., 2000, “Desing and Evalution in Tribological coatings”, *Wear*, Vol. 246 pp 20-33.
- Jayal, A.D., Badurdeen, F., Dillon Jr., O.W. and Jawahir, I.S., 2010. “Sustainable manufacturing: modeling and optimization challenges at the product, process and system levels”. *CIRP J. Manuf. Sci. Technol.* 2, 144e152.
- Machado, A.R. e Diniz E.D., 2000. "Corte a Seco, com Mínima Quantidade de Fluido e com Fluido em Abundância: Usos, Aplicações, Vantagens e Desvantagens" [Dry cutting, MQL and flooding: application advantages and disadvantages] *Machining 2000 - Fair and Congress, Proceedings in CD-ROM*, 19-14H00-1.pdf, September, [In Portuguese].
- Machado, A.R., Abrão, A.M., Coelho, R.T., da Silva, M.B., 2015, "Teoria da Usinagem dos Materiais", 3 ed., São Paulo, Blucher, v.1, 407p.
- Ramos, C.E., De Oliveira, P.A., Costa, E.S. e Machado, A.R., 2017. “Influence of Hole Depth on Force and Torque in Drilling with MQL of Grey Cast Iron”, 9^o Congresso Brasileiro de Engenharia de Fabricação - COBEF, Joinville-PR, Brasil.
- Sandvik Coromant, 1994, “Modern metal cutting – a practical handbook”, Sweden: 1. ed. 840 p. ISBN 91972299-0-3.
- Santos, S.C. and Sales, W.F. Aspectos Tribológicos da Usinagem dos Materiais, Ed. Artliber, São Paulo, 2007.
- Teixeira, C.R., 1995. “Influência dos Erros Geométricos de Afição nas Brocas Helicoidais de Aço-rápido na Qualidade dos Furos Produzidos”, Dissertação de Mestrado do Programa de Pós-Graduação em Eng. Mecânica da UFSC, Florianópolis-SC, outubro, 110 p.

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